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INSTRUMENTATION FOR OBSERVATIONS OF CONCRETE AND SOIL DAMS AND THEIR FOUNDATIONS

D. Radkevich

April 1978

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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Field observations of the condition of hydrotechnical structures play an important role in ensuring the safety and reliability of structures. Primary information about the condition of structures is obtained with the aid of measuring instruments installed in the structure. Such instruments have different purposes. Large modern structures contain up to 2 - 3 thousand units of instruments which measure physical values that characterize the stress-deformed state, linear and angular displacements, the temperature and filtra-

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INSTRUCTIONS FOR OBSERVATIONS OF CONCRETE AND SOIL DAMS AND THEIR FOUNDATIONS

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The Soviet-American Working Seminar, "Engineering Inspection and Monitoring Hydrotechnical Structures and Measuring Apparatus for These Purposes", 14 - 18 December, 1977, USA, Moscow, 1977

Field observations of the condition of hydrotechnical structures play an important role in ensuring the safety and reliability of structures. Primary information about the condition of structures is obtained with the aid of measuring instruments installed in the structure. Such instruments have different purposes. Large modern structures contain up to 2 - 3 thousand units of instruments which measure physical values that characterize the stress-deformed state, linear and angular displacements, the temperature and filtration regimes of operation of the structure and of its foundation. Both optical-mechanical measuring instruments and measuring transducers with an electrical signal are employed. The fundamental developmental tendency of measuring instruments for hydrotechnical structures consists in the development of automated measuring devices and their gradual replacement of mechanical measuring instruments. Evidently, in the near future the role of the latter will be reduced chiefly to testing the automated measuring systems.

In the USSR, work has already been carried out for many years in devising methods and means of measurement and in developing systems of monitoring structures. The first Soviet measuring transducers employing electrical signals - stream tensometers for concrete - were developed 50 years ago by Academician N. N. Davidenkov (1) and were employed in the V. I. Lenin Hydroelectric Power Plant's concrete dam on the Dnepr. The construction of this dam was completed in 1932. Subsequently, all large hydrotechnical structures in the USSR as well as foreign structures constructed with the technical assistance of the Soviet Union were equipped with Soviet measuring instruments.

Each structure equipped with measuring instruments has two control systems: the construction system and the operating system. Both systems are built in the process of construction and function jointly during construction. The construction monitoring system contains measuring instruments mounted in the body of the structure and are inaccessible for metrological testing or replacement. These measuring instruments have a guaranteed lifetime of 10 years; practically speaking, a significant part of the instruments operate normally for up to 20 years, and in individual cases for longer. The basic function of this system is to monitor the stress-deformed state of the structures and foundations during construction and during the first years of operation, as well as to ensure technological control when carrying out construction operations: pouring concrete of the structures and foundations, hardening of the concrete, laying earth in earthen dams, etc. The operating monitoring system contains measuring instruments which are accessible to technical service and which function during the entire lifetime of the structure. The basic purpose

of this system is to monitor the linear-angular displacements of structures and structural components, as well as the filtration and thermal operating regimes of the structures.

2. Measuring Inducers

The measuring inducers employed in systems of monitoring structures are standardized with respect to their output signal and the type of transmitting transducer component, which converts a mechanical value into an electrical one. The informative parameter of the signal of measuring transducers is the frequency of alternating current at the output of the transducer. Standardized stream vibrofrequency transducer modules are employed as the transmitting transducer component. These operate in the attenuated oscillation regime in a frequency range of from 1 to 2 kHz. Excitation and transmission of the signal occur over a two-wire communications link with the secondary measuring device. The excitation pulse parameters are the following: amplitude, 150 volts, length, 0.3 - 0.5 msec, minimum signal amplitude over the time of measurement, at least 10 mv. Measurement is made by a periodomer by means of determining the length of 1000 oscillations of the stream with a time delay of the beginning of reading which is a multiple of the stream oscillation period. 0.2 mm-diameter wire made of first class steel spring wire is used in the vibrofrequency induction components. This wire has a proportionality limit of at least 1600 MP. The working stresses in the wires at maximum frequency of natural oscillations do not exceed 650 MP.

The graduated characteristics of the measuring inducers with wire vibrofrequency inducer components have the following form

$$P = Af^2 + Bf + C,$$

where P is the measured value,

f is the frequency of the inducer signal,

A, B and C are coefficients which are determined during inducer graduation.

The measuring transducers of the wire vibrofrequency type used in structure monitoring systems are not employed because of a historically developed tradition, but have extremely significant advantages tested by many years of practice. Among the most important advantages are the high temporal stability of this type of transducer, discreteness of the information parameter of the signal and its total independence from changes in electrical parameters of the power supply lines, which are unavoidable during long-term operation. The total error of wire transducers during the guaranteed lifetime of the instrument does not exceed ±2%.

In addition to the transmitting tranducer component, transducers have a number of other standardized components, among which an important role is played by the line input. The body of the line input is connected with the cable housing by vulcanization, and to the transducer housing with the aid

of a conical link using epoxy glue. The electrical connections are made in glass, transit insulators soldered into the housing of the cable input. These hermetically separate the internal cavities of the inducer and the cable. Many years (since 1960) of practice in using transducers with this type of cable input has demonstrated their high reliability. In the USSR, a specially developed cable of the KRGD type, with dimensions of 2 X 1.5 mm is used for laying cable lines embedded in the body of the structures. The cable withstands an external water pressure of up to 4 MP and permits a relative elongation of up to 5%. The latter quality is extremely valuable during the use of the cable in earthen dams, where its additional protection against elongation loads is practically impossible. The outer coating of the cable and the cable strand insulation are made of rubber.

One should also note certain characteristics of measuring transducers' meteorological support among the general characteristics of measuring transducers.

All measuring transducers used in structures can be divided into two groups according to methods of meteorological certification. The first group includes temperature, strength, water level, linear displacement, and other transducers whose meteorological certification is made on the basis of standard methods and technical means of general application. The second group includes tranducers of linear deformations, internal and contact stresses, pore pressure, external dynamic loads and certain other values during whose measurement it is necessary to take into account the interaction of the transducer with the "construction" medium: soil, concrete, water, etc.; the primary measuring transducer (sensing procedure) in these measurements is the fundamental source of their error.

Transducers of the second group are made in the form of unit transducers consisting of the primary (primary transducer) and secondary (secondary transducer) transducers certified as independent measuring instruments. The primary transducer transforms a measured mechanical value into another mechanical value which the secondary transducer converts into an electrical signal. For purposes of standardization, first group transducers are used as the secondary transducer. These are certified with respect to their input value. The meteorological certification of the primary transducer is established by technical instruments used to test hydrotechnical structures and materials and duplicate the measured and influential magnitudes having standard errors in the appropriate medium. As the result of meteorological investigations of models of primary transducers, one establishes a combination of technical specifications whose satisfaction guarantees the transducers' standardized meteorological characteristics. Control over the satisfaction of these specifications is maintained by the manufacturer and agencies of the meteorological service with the aid of standard technical instruments, already without using the "construction" media.

3. Measuring Instruments for Monitoring the Stress-Deformed State of Concrete Dams, Reinforced Concrete Structures and Rock Foundations

The investigation and monitoring of the stress-deformed state of concrete are predominantly carried out by the method of measuring deformations. Stresses in the bodies of concrete dams are calculated according to the data of these

measurements. A presentation of the method of measurements and processing the results exceeds the framework of this report. It has been quite fully presented in scientific presentations and normative documents (2).

The basic measuring instruments used for the indicated purpose are linear deformation transducers of the PLDS type, whose basic technical specifications are given in Table 1.

Table 1.

Type of Transducer	Measurement Base, mm	Relationship of Outside Diameter to Base of Measurements	Range of Measurements, %
PLDS-150	150	0.167	1.5
PLDS-250	250	0.104	2.5
PLDS-400	400	0.065	2.5
PLDS-1000	1000	0.045	2.5
PLDS-2000	2000	0.022	2.5
PLDS-5000	5000	0.009	1.0

The transducer (Figure 1) consists of a telescoping housing with anchors rigidly connected to the high frequency transducing component hanger. In all standard size transducers with the exception of the PLDS-150, the working section of the hanger within whose limits the oscillations are excited is separated by an intermediate base made of two diaphragms which have very slight rigidity in the direction of the hanger. The sealing component which receives the longitudinal deformations of the transducer is made of a stainless alloy. The outside surface of the housing is protected against coupling with the concrete by a thin porous rubber membrane.

With respect to their mechanical properties, PLDS transducers are soft tensometers. Their initial hardness is determined by the resistance of the cross-section of three copper stiffeners 1.5 mm in diameter installed in the telescoping portion of the housing.

Two types of anchors are used depending upon their purpose: one type for mounting the transducers within the body of the dam and another type for the rock foundation and the dam surfaces.

The PLDS-150 transducer (Figure 2) is predominantly used for measuring steel deformations.

The basic purpose of the PLDS-250 and PLDS-400 transducers is to measure concrete deformations in the bottom of concrete dams. The transducers are mounted in flat and elongated rosettes, settling cones and devices for determining the deformative properties of concrete.

The PLDS-1000, PLDS-2000 and PLDS-5000 transducers are used for observing deformations of rock foundations as well as their monitoring crack formation and opening of joints in concrete dams. When using transducers on the surfaces of structures or the foundations, anchors are preliminarily cemented in the holes. Individual transducers or transducers assembled into a cluster are cemented during placement in a borehole with the investigated object by means of injecting the cement mixture into the anchor placement area.

The DB-4 (3) hanger, vibrofrequency stress transducer has been developed for making direct measurements of compressive stresses in concrete. The DB-4 transducer is a Karlson dynamometer equipped with an invar thermal stress compensator (Figure 3). The transducer is predominantly used for laboratory and test site investigations. It has not now been extensively extended to the practice of observing the condition of dams due to technological difficulties which arise during installation in concrete, and also because of the insufficient study of its interaction with concrete under conditions of a triaxial stress state.

Investigations of the stress-deformed state of dams provide for the determination of the dams' thermal regime. The PTS type temperature transducer is manufactured to monitor the temperature of structures and foundations. The PTS type transducer has a measuring range of from -30 to +60°C (Figure 4). The transducer contains an aluminum alloy cylinder mounted in a sealed housing and the hanger type vibrofrequency transducer component attached to the cylinder. When the transducer's temperature changes, voltage potentials arise in the steel hanger (wire) due to the difference between the coefficients of thermal expansion of the cylinder and the hanger, which causes appropriate changes in the frequency of natural oscillations of the hanger.

The PTS transducer is used for long-term monitoring of the temperature of structures and foundations of all types. It is also used for technological purposes in processes of cooling concrete.

In order to observe the opening of seams in concrete dams and deformations of rock foundations, linear displacement transducers of the PLPS-3, PLPS-10, PLPS-30 and PLPS-100 types are used. These have measurement ranges of 0 - 3, 0 - 10, 0 - 30, and 0 - 100 mm, respectively.

The transducer (Figure 5) contains a hanger-type vibrofrequency transducer element connected on one side to the housing and on the other to a scale whose free end is attached to a pin which is movable relative to the housing. Movement of the pin causes changes in the elongational force in the hanger (wire) and in the frequency of its natural oscillations.

The PLPS-3 and PLPS-10 transducers differ only with respect to the rigidity of their dial springs.

The PLPS-30 and PLPS-100 transducers are built on the basis of the PLPS-10 transducer with reducing devices attached to it. These provide step-down ratios of 1:3 and 1:10, respectively.

With the aid of various attachments, PLPS-type transducers are installed in the seams between concrete blocks, at the point of contact of concrete structures with the rock foundation, in the boreholes drilled in the foundations, on seams and cracks which work to the surface of the structures and foundations, in cavities, shafts, galleries, etc. In addition to being used for long-term monitoring of structures, PLPS-type transducers are also used for making technological measurements of the opening of seams in concrete dams in the process of concrete pouring.

Force transducers of the PSAS type (Table 2) are used to monitor forces in the reinforcing rods of reinforced concrete structures.

Table 2

Type of Transducer	Diameter of Attached Reinforcing Rod, mm	Range of Measurements, kN
PSAS-20	20	90
PSAS-28	28	180
PSAS-40	40	360

The transducer (Figure 6) contains a cylindrical housing with extenders made of variable profile reinforcing steel welded into it. A hanger-type vibrofrequency transducing component is housed within the housing. The measured force causes elongation of the housing and alters the frequency of natural oscillations of the hanger (wire).

The PSAS-type transducer is installed either directly on the working gear or parallel to it in the form of a "floating" rod. The extenders of the transducer are welded together with the reinforcing rods by means of a joint without applied components. The outside surface of the transducer housing is coated with a porous rubber coating in the area where the wire transducer component is installed. The coating prevents union with the concrete.

The basic use of type PSAS transducers is to monitor the stressed state of a rod in the construction joints of reinforced concrete structures: combined-type hydroelectric power plant buildings, the pressure laden walls of lock chambers, etc.

4. Measuring Instruments for Monitoring the Stress-Deformed State of Earthen Dams and Foundations

The stressed-deformed state of earthen dams and foundations is predominantly monitored during construction and the first years of operating the structures, i.e., during the intensive occurrence of ground consolidation processes. The most widely employed measurements in this case are measurements of local linear deformations, pore pressure, normal stresses in the dirt massif, normal and shear stresses at the point of contact of concrete structures with the dirt, and temperature.

Displacement transducers of the PLPS-30 and PLPS-100 type with base-forming devices are used to monitor local linear deformations of the dirt. The base lengths are set at from 2 to 10 m. In order to expand the limits of measuring deformations, D-3M-type transducers with a measuring range of from 0 to 200 mm are also used (Figure 7).

The base-forming devices contain anchors and a telescoping housing which is coated. These reduce shear stresses at the point of contact of the transducer with the dirt.

In order to monitor the vertical and horizontal deformations within areas of the dam body, inclinometers (tilt meters) are used. A characteristic of the inclinometric method of measurements employed in the USSR is that the inclinometer is fixed at marks placed within the inclinometric tubes in the process of making the measurements, and at each stop of the instrument the angles of inclination of the axis of the inclinometer and the distances between marks are measured. The results of measurement are processed precisely as during the poligonometric observations.

The inclinometric device (Figure 8) is mounted on the chassis of a vehicle and contains the inclinometer, a winch with logging cable, and the electronic measuring apparatus. The winch is driven from the vehicle motor. Measuring transducers of the angle of inclination oriented in two mutually perpendicular planes are installed in the inclinometer. The transducer which is used to measure distances between marks and the electronic unit which preliminarily converts signals of the transducers are also installed in the inclinometer.

The inclinometer is 2.5 m long and the initial distance between marks is 2.2 m. Measurements are made when the inclinometer rises from the lower element of the tube installed in the foundation of the dam. The inclinometer stops automatically at each pair of adjacent marks. The results of measurements are displayed on a digital panel and are recorded on perforated tape for computer processing. Inclinometers of this type are being used at dams at the Charvaksk and Nurek hydroelectric power plants (3, 4).

Measurements of pore pressure are made with pressure transducers with a special probe-filter. PDS-0, 3P; PDS-1P; PDS-3P and PDS-10P type transducers are manufactured. They have measurement ranges of 0 - 0.3, 0 - 1, 0 - 3, and 0 - 10 MP, respectively.

The transducer (Figure 9) contains a hermetically sealed housing, the console cylindrical sensor attached within it, inside of which is a wire transducer component and a separating diaphragm welded along the housing to the housing and lying at the free end of the sensor component. Measured pressure is past via the diaphragm to the sensing component, compresses it, and by reducing tension in the wire alters the frequency of the wire's natural oscillations.

Transducers are mounted both in the earthen pile in the process of building it up and in boreholes drilled in the foundations or body of the dams. During

installation in the earth pile, additional flat filters are used, for example, fiberglass filters (Figure 10). During installation in boreholes, additional filters are formed by means of a thin layer sand pile and plug the borehole around the transducer; after installing the transducer, the borehole is buffered with a material having lower permeability to water than the surrounding soil. The role of the additional filter consists in reducing the concentration of ground stresses in the area of installing the transducer, increasing the active filtration surface, and averaging the measured pressure field.

Normal stresses in the dirt massif are measured by EDNG-type stress transducers (Figure 11), which consist of an elastic (one word illegible) rubber capsule with the attached, type PDS pressure transducer described above. The internal cavity of the capsule, formed by two sheets of rubber, is welded along the contour and connected by connectors uniformly distributed over its area. The cavity is filled with a non-freezing fluid. The capsule is 400 mm in diameter and 10 mm high. Ground stress measured normally to the capsule surface is converted into a pressure of the fluid which fills the capsular cavity and is then converted into an electrical signal.

The EDNG-type transducer has significant meteorological advantages in comparison with rigid transducers with membranous or dynamometric sensor components. Physically, the advantages (5, 6) are due to the fact that the transducer capsule has an extremely low relative height - 1:40, high rigidity in the direction of the measured stresses, and does not offer additional resistance to ground deformations in the other directions. Specifically, the transducer does not prevent the development of heterogeneous deformations in the soil, which lead to the appearance of a so-called orientation effect during the use of rigid membranous transducers; i.e., a dependance of the measurement results on the position of the membrane. During installation in the ground, the transducer usually makes it possible to use a placement technology and ground packing method in common for the given dam component.

Stress transducers (3) are used to measure normal stresses in stone-faced dam prisms. These are two steel plates between which three compressive force transducers are placed. The device (Figure 12) is 1 m in diameter and 0.2 m high; deformation of the force transducer in the direction of the measured stresses is 100 μ with a normal load of 4.5 MP.

Stresses are measured at the contact of the concrete structures with the earth by stress measuring transducers of the GD type, which have a measurement range of from 0 - 0.4 MP to 0 - 0.6 MP. The transducer (Figure 13) has a circular membrane with a wire transducer component attached with the aid of lugs. Bending the membrane under the effect of the measured contact stresses causes the lugs to turn and alters the wire's tension.

The transducers are mounted on concrete structural surfaces in contact with the ground. The high degree of heterogeneity of field of the contact stresses necessitates placing the transducers in groups of no less than three per measuring point.

A more effective instrument for monitoring contact stresses is the device (7), which is a rigid rectangular-shaped plate placed face down on the surface of the structure and operating as a sensor of forces oriented in the directions of both normal and shear stresses. Force transducers of the SDT type with a range of measurements of 0 - 15, 0 - 30, and 0 - 50 kN are used for this purpose.

The transducer (Figure 14) contains a cylindrical sensing component with the coaxially mounted wire transducer component within it. The transducer housing has a thread on one end for connecting it to the frame attached to the body of the structure and has a steel ball bearing on the other end. The bearing is in contact with the plate. The plate is fixed in the initial position by a system of springs which do not influence the measurement results.

5. Measuring Instruments for Monitoring Filtration

Observations of the filtration regime of functioning of structures and foundations are made both during construction and during operation. The basic values that are measured during filtration observations are pressure, level of the free surface of flow filtration, flow rates in drainage system collectors, temperature of the filtering water, and the concentration of dissolved and suspended substances in water samples.

Piezometers of various designs are used to measure filtration pressure and levels of depression surfaces. The choice of the different designs is determined by the type of structure, the depth of the water intake, hydrogeological conditions and other circumstances.

In the USSR, a great deal of experience has been accumulated in building and operating piezometers on hydrotechnical structures, including the use of piezometers to determine the filtering properties of foundations, taking samples for hydrochemical analyses, etc. Analysis of the designs of piezometers of different types and of the technology of carrying out work on their construction and operation exceed the framework of this report, which predominantly applies to the remote measuring instruments which are used.

Direct measurements of water levels are made in piezometers with the aid of electrical and electroacoustical probes and pressure transducers of the PDS type, described in the previous section, are employed in automated measuring systems. The transducer is lowered to a fixed point in the piezometer below the zone of water level fluctuations and hydrostatic pressure is measured. In the process of operation, the transducer is accessible for calibration and replacement and a test can be carried out in the borehole itself by the method of altering the depth of immersion of the transducer.

PDS-type transducers are also used to measure pressure in pressurized piezometers. One can test the transducers both under stationary conditions and directly in the pressurized piezometer head with the aid of a portable tester having a test manometer.

Flow rates are measured in non-pressurized drainage collectors with the aid of measuring spillways and are measured in pressurized drainage collectors

with Venturi flow meters or diaphragmatic flow meters. In the former case, one measures the level of flow surface ahead of the spillway, and in the latter case the pressure differential. In order to measure water level before the spillway, IVD-type level sensors are used. These are also used in hydrostatic levelling systems. IVD-type transducers are built with measuring limits of 0 - 30, 0 - 100, and 0 - 300 mm.

The transducer (Figure 15) contains a cylindrical vessel partially filled with fluid, the load partly immersed in the fluid and attached to the vessel via the wire force transducer. Measurement of fluid level leads to a corresponding change in the force measured by the force transducer. In the force transducer used for the indicated purpose, the wire of the transmitting transducer component receives the entire measured force. This ensures extremely high stability of the given measuring instrument since the frequency of the natural oscillations of the wire in this case depends very little on changes in its length and is wholly determined by the measured force.

A transducer has been developed to measure pressure differentials in which the wire transducer component also functions in the force measuring regime. Ranges of the measured pressure gradients are 0 - 10 and 0 - 30 kP.

The PTS-type temperature transducer described in Section 3 is used to measure the temperature of filtration flows. The transducer can be placed in boreholes, drainage collectors, etc. Transducers used in the construction monitoring system can also be placed in the body of the structure and foundation without possible access to them.

With respect to monitoring the concentration of dissolved and suspended substances in the filtering water, then these parameters are chiefly determined by the method of sampling with subsequent analysis under laboratory conditions. Practically no remote measuring instruments are as yet employed in these observations.

6. Measuring Instruments for Monitoring Linear and Angular Displacements of Structures and Foundations

Observations of linear-angular displacements of structures and foundations provide for the measurement of settling, horizontal displacements, and slopes. A geodesic monitoring system is built at each structure. The amount of observations and the composition of technical instruments are determined by the class of the structure and by its design and geological features. The task of this report does not include the description of the conventional geodesic methods and instruments for making measurements (8, 9, 10) used at the structures. A number of devices which are used to automate observations is examined. Recently, laser measuring technology has been rapidly developing. This technology makes it possible to make highly accurate measurements, including automated ones. However, the automation of linear-angular measurements based on mechanical instruments employing electrical transmitting transducers is still widespread because of the simplicity of servicing and high operating reliability under the specific conditions of hydrotechnical facilities.

A hydrostatic levelling system is used to monitor settling of structures and foundations. This system contains sealed fluid level transducers of the IVD type (Figure 15) installed in the monitored points of the structures and interconnected by two tubes. One tube is filled with the working fluid and ensures an identity of fluid level in all transducers. The second tube serves to maintain identical air pressure in the system, which is usually somewhat higher than atmospheric pressure. The system is installed on the surfaces of structures, in cavities or inspection galleries for operating monitoring. The systems are tested periodically by geodesic methods. Installation of the system in the body of the structure and foundation without access to it is permitted for monitoring during construction. For example, such a method of system installation was used during construction at one of the locks where observations are made of warps in the reinforced concrete lock bottom.

Observations of slopes of concrete structures and rock foundations are made with the aid of KSD-type inclination angle transducers, which have a measurement range of ±10 mrad. The transducer (Figure 16) contains a sealed housing, a load immersed in fluid and attached to the flexible housing suspension, and two wire force transducers whose sensing components are connected to the suspension and are oriented in mutually perpendicular directions to the plane perpendicular to the suspension. When the device is inclined, the transducers receive forces proportional to the angle of inclination.

Inclination angle transducers are installed in cavities, shafts or tubes within the structures and foundations and monitor inclination in two planes with their aid. As a rule, these planes correspond to the longitudinal and transverse vertical sections of the structure.

A measuring method has been developed to automate measurements of horizontal displacements. This method is a development of methods based on the use of a wire elongated along the observation section: direct and inverse plumbings of the horizontal wire on floating supports (10).

The method consists in installing force transducers at monitoring points in the structure. These transducers are connected to a wire and cause it to deviate from the straight line connecting its anchoring points. In this instance the axial line of the wire is converted into a broken line with small breaking angles. The force measuring transducers are oriented in the direction of the measured displacements. The direction of the observation line can be near both the vertical and the horizontal, and if necessary can have a certain curvature (for example, when monitoring the horizontal displacements of arcing dams).

One anchor point of the wire is obligatorily attached to a rib element or a relatively immobile point of the structure (foundation), whose coordinates can be periodically tested geodesically. The second anchoring point can also be a rib or calibration point, and if this is impossible, then the vector cosines of the latter beyond this point in the elongation wire sector should be known. This is most simply done with a vertical installation of the wire, when the lower anchoring point is placed on the practically indeformable area of the foundation while the upper point is placed on the floating part of the

unloaded device used for the inverse plumbs (Figure 17).

The measured forces are related to displacements of the monitored points of the structure by a system of linear equations which represent the conditions of equilibrium of the forces acting on the wire at the controlled point of the structure. In the case of fixed coordinates of the anchor points, the system of equations for (n-1) of the monitored points has the following form:

$$-\frac{\Delta X_0}{l_1} + \left(\frac{1}{l_1} + \frac{1}{l_2}\right)\Delta X_1 - \frac{\Delta X_2}{l_2} = \frac{\Delta P_1}{S}$$

$$\cdots$$

$$-\frac{\Delta X_{i-1}}{l_i} + \left(\frac{1}{l_i} + \frac{1}{l_{i+1}}\right)\Delta X_i - \frac{\Delta X_{i+1}}{l_{i+1}} = \frac{\Delta P_i}{S}$$

$$\cdots$$

$$-\frac{\Delta X_{n-2}}{l_{n-1}} + \left(\frac{1}{l_{n-1}} + \frac{1}{l_n}\right) - \frac{\Delta X_n}{l_n} = \frac{\Delta P_{n-1}}{S}$$

where: ΔX_i - displacements of monitored points when = 1, -1;

ΔX_o, ΔX_n - displacements of anchor points of the wire, assumed to be zero during the entire period of measurements or are periodically determined by geodesic means;

l_i - lengths of wire sections between the monitored points;

ΔP_i - increment of measured force over the period of observations from the initial installation of the wire;

S - wire elongation force.

In the case of vertical installation of the wire with loading of the floating device, the latter equation in the system acquires the following form:

$$-\frac{\Delta X_{n-2}}{l_{n-1}} + \frac{\Delta X_{n-1}}{l_{n-1}} = \frac{\Delta P_{n-1}}{S}$$

Sensitivity of the described measuring system to displacements is:

$$\delta l = \frac{\delta P}{S} \cdot l$$

where δP is sensitivity of the measured force transducer.

The described measuring system can be a two component system. In this case, two force transducers are installed at each monitored point of the structure and are oriented in mutually perpendicular directions. The systems of equations which relate the displacements to the measured forces are independent and have

the same factor matrix. In this case, when one has horizontal installation of the wire, settlement is measured in addition to horizontal displacements. However, the difficulty of making the measurement of settlement is lower than that of measuring the horizontal displacements because of the effect of instability of wire weight which is due to the condensation of moisture on the surface of the wire. The bicomponent measuring system (11) installed in the concrete spillway dam cavity has a horizontal wire 400 m long under a·tension of 2 kN, has nine monitoring points spaced every 40 m, and has force measuring transducers with a sensitivity of 0.01 $\frac{N}{Hz}$. With these parameters, $\delta l = \pm 0.2$ mm. The force transducers have a wire vibrofrequency transducing element which fully receives the measured force and has an instrument error no greater than 0.2%.

The advantages of the described measuring system are efficiency of monitoring dam displacements and dam foundations. This advantage is most fully realized under conditions of automating measurements with the use of a computer.

REFERENCES

1. Davydenkov, N. N. Strunnyy metod izmereniya deformatsiy. (The Wire Method of Measuring Deformations). GTTI, Moscow, 1933.

2. Eydel'man, S. Ya. Posobiye po metodike obrabotki dannykh naturnykh issledovaniy betonnykh gidrosooruzheniy. (A Manual on a Method of Processing Data of Field Investigations of Concrete Hydrotechnical Structures). Published by "Energiya", Leningrad, 1975.

3. Radkevich, D. B. Monitoring-Measuring Apparatus for Field Investigations of Hydrotechnical Structures. Trudy koordinatsionnykh soveshchaniy po gidrotekhnike. (Transactions of the Coordinating Meetings on Hydrotechnology). No. 63, Published by "Energiya", Leningrad, 1971.

4. Darkshevich, Ya. N., M. N. Lednev, S. G. Satanovskiy, A. I. Tsarev. Monitoring the State of a High Stone-Earth Dam Core During Construction. "Gidrotekhnicheskoye strontel'stvo", No. 3, 1973.

5. Kheyfits, V. Z. Izmereniye napryazheniy v gruntakh. (Measuring Stresses in Soils). Informenergo, Moscow, 1973.

6. Kheyfits, V. Z., I. R. Petrashen'. Datchik nepryazheniy grunta. Material VIII Mezhdunarodkogo kongressa po mekhanike gruntov i fundamentostroyeniyu. (An Earth Stress Sensor. Material of the VIII International Congress on Soil Mechanics and Foundation Building). Stroyizdat, Moscow, 1973.

7. Tsarev, A. I. Measuring Shear Stresses at the Point of Contact of a Structure with Non-rocky Soil. Trudy koordinatsionnykh soveshchaniy po gidrotekhnike, No. 29. Published by "Energiya", Leningrad, 1966.

8. Brayt, P. I. Geodesic Methods of Measuring Deformations of Foundations and Structures. Published by "Nedra", Moscow, 1965.

9. Uchingus, A. A., V. P. Bombchinskiy. Kontrol'no-izmeritel'naya apparatura gidrotekhnicheskikh sooruzheniy. (Control-Measuring Apparatus for Hydrotechnical Structures). Gosstroyizdat, Moscow, 1954.

10. Bombchinskiy, V. P. Determining Planned Shifts of Hydrotechnical Structures Relative to the Extension Line. Information from Higher Educational Institutions. Geodeziya i aerofotos'yemka. No. 4, Moscow, 1958.

11. Radkevich, D. B., I. K. Konovalov. A System of Remote Measurement of Spatial Deformations of Hydrotechnical Structures and Foundations. Trudy koordinatsionnykh soveshchaniy po gidrotekhnike. (Transactions of a Coordinating Meeting on Hydraulic Technology). Field Investigations of Hydrotechnical Structures. Published by "Energiya", Leningrad, 1975.

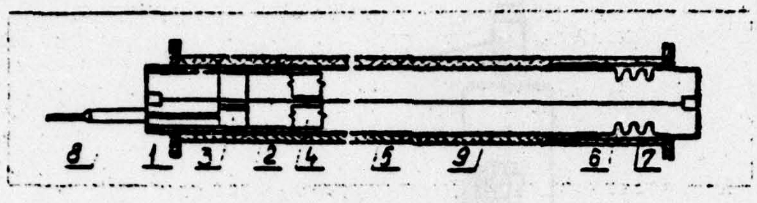

Figure 1. PLDS-type linear deformation transducer
1 - anchor
2 - wire
3 - electromagnet
4 - intermediate brace
5, 7 - housing
6 - siphon
8 - cable inlet
9 - protective coating.

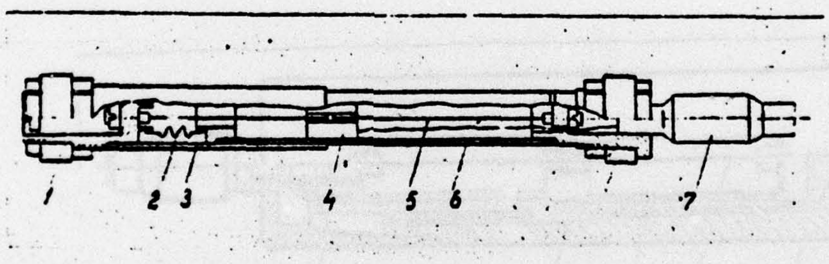

Figure 2. PLDS-150 type linear deformation transducer
1 - anchor
2 - siphon
3,6 - housing
4 - electromagnet
5 - wire
7 - cable inlet

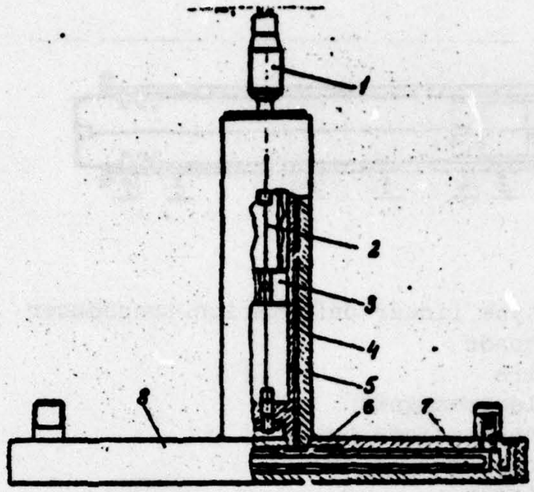

Figure 3. DB-4-type concrete stress transducer
1 - cable inlet
2 - wire
3 - electromagnet
4,8 - housing
5 - sensitive component
6 - diaphragm
7 - temperature compensator.

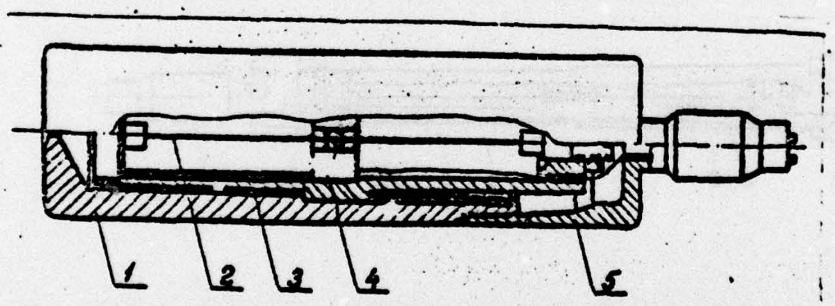

Figure 4. PTS-type temperature transducer
1 - housing,
2 - wire,
3 - sensitive component
4 - electromagnet
5 - cable inlet.

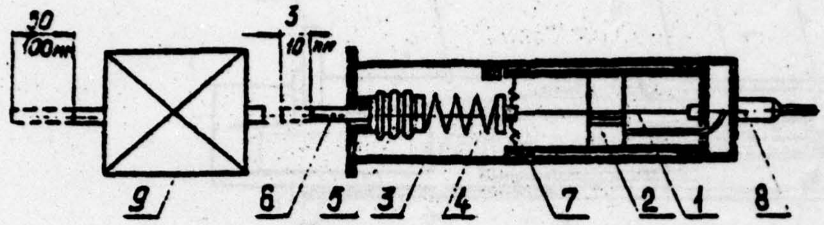

Figure 5. PLPS-type linear displacement transducer
1 - wire,
2 - electromagnet
3 - spring
4 - housing
5 - siphon
6 - shaft
7 - support
8 - cable inlet
9 - reducer.

Figure 6. PSAS-type force transducer
1 - housing,
2 - wire,
3 - electromagnet
4 - cable inlet
5 - extender.

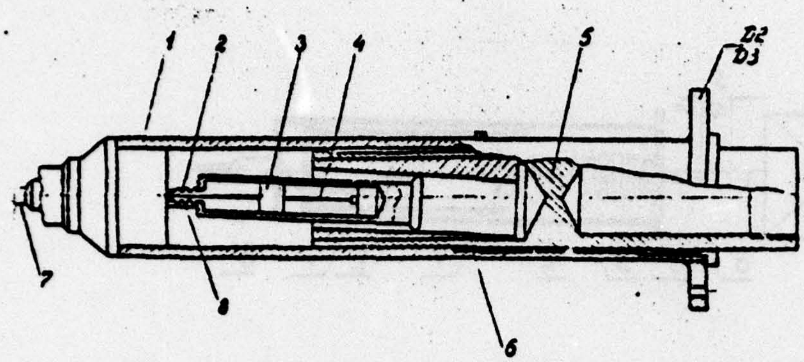

Figure 7. D-3M type linear displacement transducer
1 - housing,
2 - siphon,
3 - electromagnet
4 - wire,
5 - shaft,
6 - guides,
7 - cable inlet,
8 - flat spring.

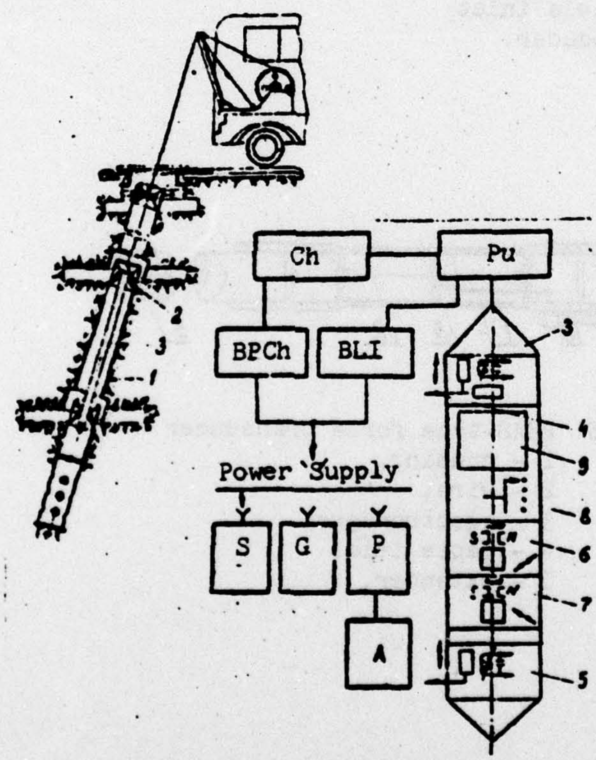

Figure 8. Inclinometric installation
1 - inclinometric tube,
2 - mark,
3 - inclinometer,
4, 5 - measuring transducer of distances between marks,
6, 7 - inclination angle measuring transducers,
8 - remote commutator,
9 - electronic signal convertor unit.

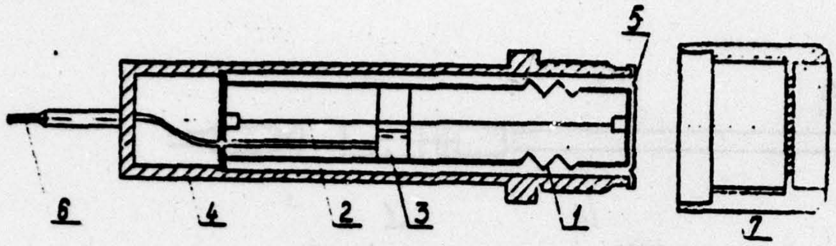

Figure 9. PDS-type pressure transducer
1 - sensitive component,
2 - wire,
3 - electromagnet,
4 - housing,
5 - diaphragm,
6 - cable inlet,
7 - sensor with filter.

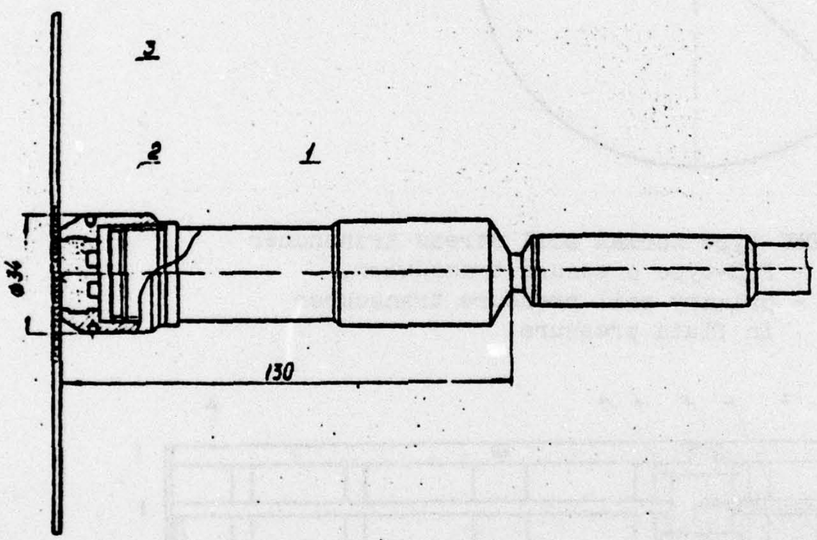

Figure 10. PDS-type pressure transducer with additional filter for measuring pore pressure in piled dirt.
1 - transducer,
2 - sensor with filter,
3 - extra filter made of fiberglass.

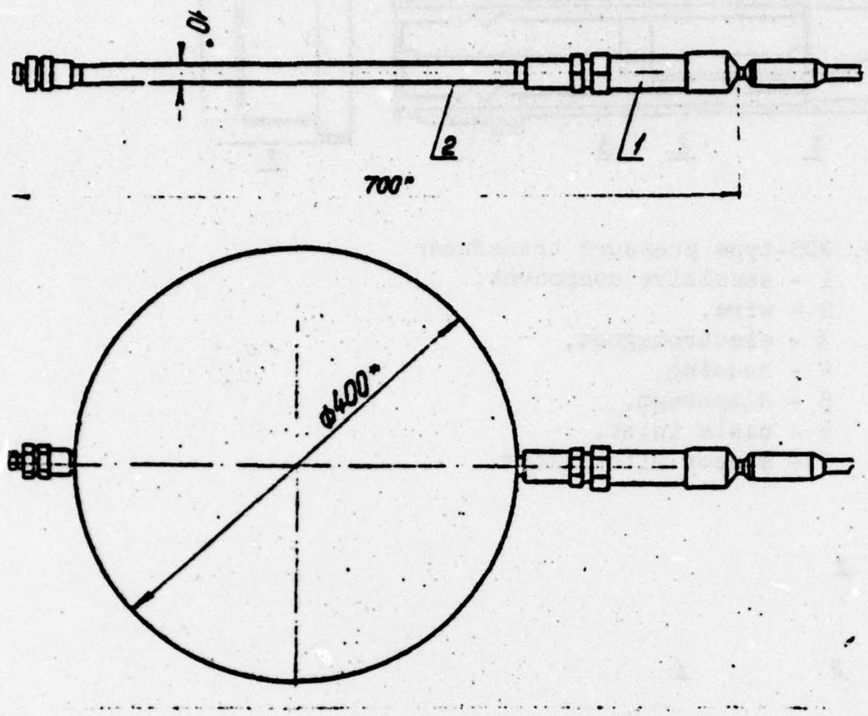

Figure 11. EDNG-type normal soil stress transducer
1 - PDS-type pressure transducer,
2 - primary soil pressure transducer
in fluid pressure.

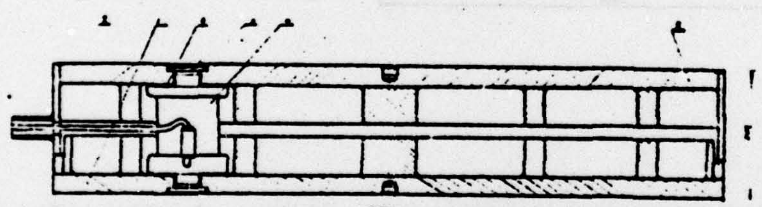

Figure 12. DKN-type transducer for normal stone-face stresses
1, 2 - plate,
3 - damper,
4 - force transducer,
5 - packing,
6 - copper cladding.

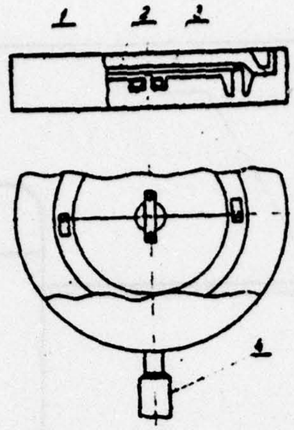

Figure 13. GD-type normal soil contact stress transducer
1 - housing,
2 - wire,
3 - top,
4 - cable inlet.

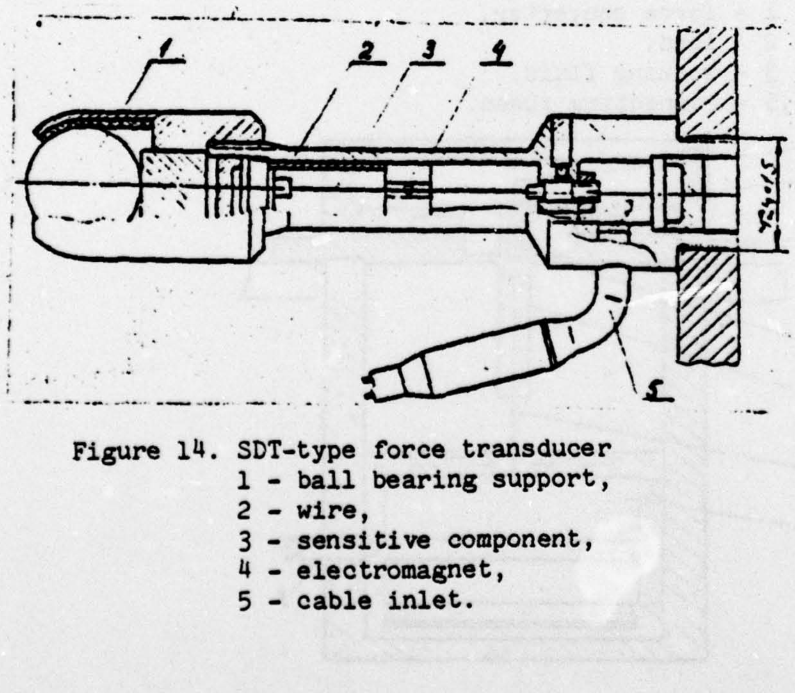

Figure 14. SDT-type force transducer
1 - ball bearing support,
2 - wire,
3 - sensitive component,
4 - electromagnet,
5 - cable inlet.

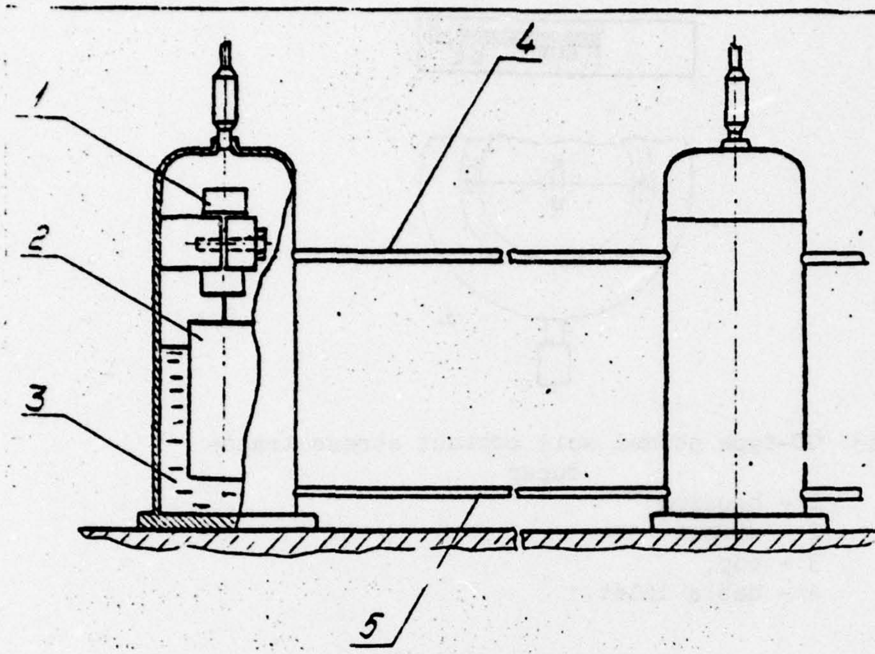

Figure 15. IVD-type level transducer
1 - force convertor,
2 - load,
3 - working fluid,
4,5 - connecting tubes.

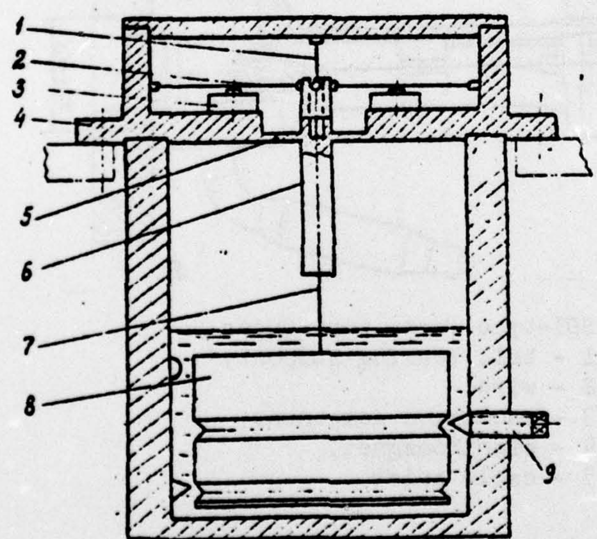

Figure 16. KSD-type bicomponent slope transducer
1, 7 - flexible suspension, 4 - housing,
2 - force transducer wire, 5 - elastic joint,
3 - electromagnet, 6 - shaft,
8 - load,
9 - arrestor.

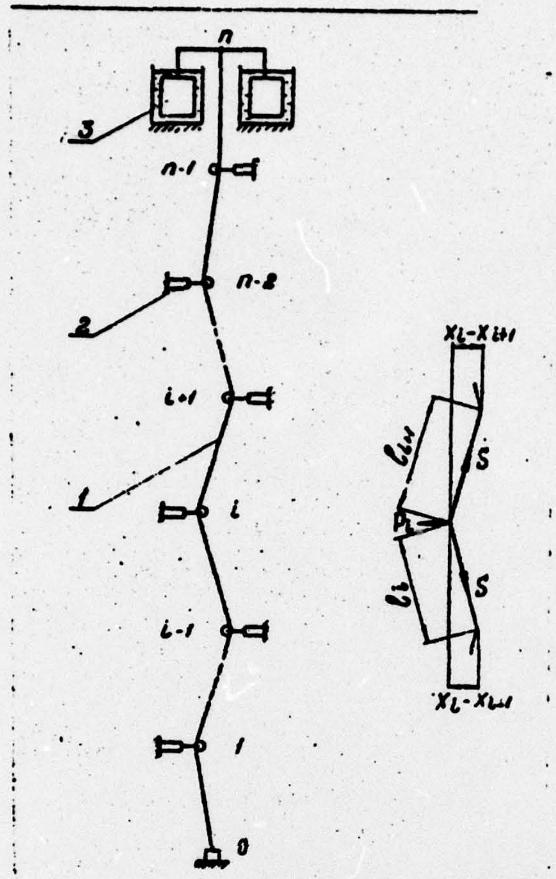

Figure 17. Diagram of horizontal displacement measurements

1 - wire,
2 - force transducers,
3 - elongator.